Simulations and Analysis of Sagged Cables/Mass Suspensions and Beams Subject to Flow Induced Vibrations

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LONG-TERM GOALS

The long-term goals of this research are to: (1) Develop and establish direct numerical simulation (DNS) methods for flow-induced vibration of flexible structures, (2) Develop a theory that connects the hydrodynamic parameters of the wake and the structure's vibrations, and (3) Develop reduced dynamical models for predicting the dynamics of the coupled system.

OBJECTIVES

The general objective of the present program is to bridge the gap that exists between studies of nonlinear dynamic models for general type cables and direct numerical simulations of flow past simple string/beam models. The former typically assumes a simplistic or empirical representation of excitation forces but provides very accurate models for the nonlinear dynamic response of the cable allowing realistic description of both steel cables and synthetic cables with nonlinear tension-strain relationship. The latter, on the other hand, assumes simple string/beam linear models but provides an accurate description of pressure and viscous forces, albeit (at present) in the low Reynolds number regime. The specific objectives of our work are to:

1. Develop a hierarchy of simulation models of cables consisting of linear three-dimensional, weakly nonlinear, and fully nonlinear responses.
2. Incorporate geometric changes and nonlinear/hysteric tension-strain relationships into the models.
3. Develop a free-surface formulation and study combined effects of shear and waves with multiple frequency response.
4. Study the response of catenary risers to VIV in conjunction with parallel experimental efforts.
5. Study the response of cables/risers with attached bodies following earlier experimental work at NRL.
6. Construct low-dimensional nonlinear dynamical models for prototype cases.

APPROACH

The technical approach in addressing the aforementioned issues consists of two main parts: (1) The development and implementation of high-order numerical methods for DNS in time-dependent domains, and (2) The construction of reduced dynamical systems using proper orthogonal decomposition methods. In the first category, we have developed spectral methods on unstructured grids and two different ways of treating moving domains. The first one uses a boundary fitted

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coordinate system, and the second uses a third reference frame moving at an arbitrary velocity – the so-called Arbitrary Lagrangian Eulerian (ALE) formulation. In the second category, we have developed the equivalent method of snapshots to extract the most energetic modes of an unsteady field in both stationary and moving domains.

WORK COMPLETED

We have derived the generalized governing equations of motion for a general cylindrical structure with sag and have obtained a hierarchy of simulation models of cables consisting of linear three-dimensional, weakly nonlinear, and fully nonlinear responses. We have parallelized the unstructured code NEKTAR-ALE and have assigned the solution of the structure's equations to a separate set of processors for enhanced modularity. In order to validate the new formulation we have repeated simulations of the laminar flow past a linear cable and compared with our previous results. In addition, we employed the new formulation for a systematic study of a project related to “the energy-harvesting eel” that the Program Manager (Dr. T.F. Swean) suggested to us.

RESULTS

We obtained detailed DNS results of flow past flexible cables and beams at Re=1000 and of stationary cylinders at Re=3900 and have analyzed the results. We have obtained the following findings:

1. Unlike the laminar regime, in the early turbulent regime the amplitude of the crossflow vibration is about one diameter for cables and beams, consistent with the experimental data, and only 0.75 diameters for the rigid freely oscillating cylinder.
2. For the rigid cylinder the flow response corresponds to parallel shedding but for the beam and cable a mixed response consisting of oblique and parallel shedding is obtained caused by the modulated traveling wave motion of the structure.
3. The mixed shedding pattern, which alternates periodically along the span, can be directly related to the spatio-temporal distribution of structure's forces.
4. All cases simulated showed an inertial subrange, with the spectrum of the rigid (moving) cylinder exhibiting very pronounced superharmonics.
5. The correlation lengths of cables and beams are qualitatively and quantitatively different than those of the rigid (moving) cylinder.
6. The turbulent wake of stationary cylinders was found to be low-dimensional by studying phase-averaged statistics and the eigenspectrum of the vorticity covariance matrix. The results suggest that a dynamical model would require of the order of twenty modes to describe the near-wake dynamics with reasonable accuracy for Re up to 5000.

IMPACT/APPLICATION

Our work has established a new area of DNS for flow-structure interactions and has produced the first ever such results both in laminar and turbulent regime. New findings have been obtained, such as the mixed traveling/standing wave response for vibrating cables, which has become the focus of several experimental and modeling efforts. With the current accelerated computational initiatives and simultaneous advances in algorithms and software, we expect that these methods will become very efficient so that they can be used effectively in the design process by the navy labs and the industry.

TRANSITIONS

Some of the findings related to long cables regarding shear flow effects and multi-moded response and the detailed spatio-temporal distribution of forces on the vibrating structure are directly useful in application of the offshore industry. We are in the process of working with a consortium of oil industries in US and with Norsk Hydro (Norway) to address their specific problems using the techniques we have developed. In addition, we have released our code NEKTAR to many other Universities and national labs, including: Cornell University, Florida State University, Oak Ridge National Labs, University of Wisconsin, Imperial College, Boeing, Inc., Penn State University, Washington State University, Nielsen Inc., Sandia National Labs, etc.

RELATED PROJECTS

We have worked closely with experimental groups funded by the same Division under the direction of Dr. T.F. Swean. In particular, we have had interactions with Professors Triantafyllou and Yue at MIT, Professor Gharib at Caltech, Professor Williamson at Cornell, and Professor Olinger at WPI.

PUBLICATIONS

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